

(19)



(11)

EP 1 745 310 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention
of the grant of the patent:

08.05.2019 Bulletin 2019/19

(51) Int Cl.:

G01V 3/08 (2006.01)

(86) International application number:

PCT/US2005/004586

(21) Application number: **05713484.3**

(22) Date of filing: **11.02.2005**

(87) International publication number:

WO 2005/114261 (01.12.2005 Gazette 2005/48)

(54) **AUTO-DEEP SCAN FOR CAPACITIVE SENSING**

AUTO-TIEF-SCAN FÜR DIE KAPAZITIVE MESSUNG

AUTO BALAYAGE EN PROFONDEUR POUR DÉTECTION CAPACITIVE

(84) Designated Contracting States:
DE FR GB

(30) Priority: **14.05.2004 US 846337**

(43) Date of publication of application:
24.01.2007 Bulletin 2007/04

(73) Proprietor: **ZIRCON CORPORATION**
Campbell, California 95008 (US)

(72) Inventor: **MILLER, Lawrence, F.**
Los Gatos, CA 95032 (US)

(74) Representative: **Gill, David Alan et al**
WP Thompson
138 Fetter Lane
London EC4A 1BT (GB)

(56) References cited:
EP-A- 1 341 005 US-A- 5 352 974
US-A- 5 812 057 US-A- 5 917 314

EP 1 745 310 B1

Note: Within nine months of the publication of the mention of the grant of the European patent in the European Patent Bulletin, any person may give notice to the European Patent Office of opposition to that patent, in accordance with the Implementing Regulations. Notice of opposition shall not be deemed to have been filed until the opposition fee has been paid. (Art. 99(1) European Patent Convention).

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0001] This invention relates to an electronic sensor, and, in particular, to a sensor suitable for detecting the location of an object behind a variety of surfaces, such as walls, floors and other non-electrically conductive structures (but not limited to building structures). More specifically, the invention relates to an electronic sensor useful to detect centerlines and edges of wall studs, floor joists, and the like.

2. Description of the Prior Art

[0002] U.S. Patent No. 4,464,622 entitled "Electronic wall stud sensor," issued Aug. 7, 1984, discloses an electronic wall stud sensor particularly suitable for locating a stud positioned behind a wall surface. (A "stud" is a structural member of a building to which an interior wall surface such as wall board or paneling is affixed.) Typically in the U.S., "2-by-4" wooden studs are used in construction. Nominally, a 2-by-4 stud is 51 mm (2 inches) wide and 102 mm (4 inches) deep and of any suitable length. The actual dimensions of a 2-by-4 are more typically 38 mm (1 ½ inches) wide and 89 mm (3 ½ inches) deep. Use of English (inches) units and U.S. stud sizes here is in conformance with U.S. construction practice and is not intended to be limiting, but is only illustrative. Finding studs is a typical problem for building repairs, picture hanging, etc.

[0003] The sensor detects the stud by measuring a change in capacitance due to a change in the dielectric constant along the wall. Due to the placement of the studs, a wall surface exhibits changing dielectric constants while the sensor is moved along the wall surface. The sensor includes a plurality of capacitor plates, a circuit for detecting changes in the capacitance, and an indicator.

[0004] The plurality of capacitor plates is mounted in the sensor such that they can be positioned close to a wall's surface. When the capacitor plates are drawn along the surface, the circuit detects a change in the capacitance of the plates due to a change in the average dielectric constant of the surface. The capacitor plates are used to measure the effective capacitance or change in capacitance of a wall. Before detection begins, the sensor first performs a calibration to null out the effect of a wall in the absence of a stud.

[0005] The capacitor plates are composed of a center plate and a symmetric pair of electrically connected edge plates. A difference in capacitance between the center and edge plates is used to determine the location of the edge of a stud. The centerline of the stud is then determined by finding both the left and right edges of the stud and then measuring to the middle of the distance between the edges. Thus, multiple measurements must be made in order to determine the centerline of the stud. The indicator indicates a change in capacitance of the capacitor plate, thereby alerting an operator to the wall stud position. The indicator also alerts the operator when calibration is occurring.

[0006] While this procedure is effective in determining the centerline of a stud, significant errors in determining the location of the stud's edges can occur. One factor is the depth of the stud behind the surface. Due to the thickness of the sheetrock (also referred to as gypsum wall board and which has a thickness of 16 mm or equivalently 5/8 of an inch) or other wall surface material, a "ballooning" effect may distort the perceived width of the stud. The closer a stud is positioned to the surface, the wider the stud will appear when sensed in this way. Similarly, the farther or deeper a stud is positioned, the narrower the stud will appear. This ballooning effect is exacerbated when the sensitivity of the sensor is increased to aid in detecting deeper studs. The ballooning may be asymmetric due to electrical wires, metallic pipes and other objects in close proximity to the stud, which in turn may lead to a reduced ability to accurately determine a stud's centerline. In the case of extreme ballooning, location of an edge of a stud can be inaccurately indicated by as much as 51 mm (2 inches). Similarly, the centerline of the stud may be so inaccurately indicated that it is completely off the actual stud location.

[0007] A first method of compensating for the ballooning effect is shown in U.S. Patent No. 6,023,159, entitled "Stud sensor with dual sensitivity," issued February 8, 2000. Unfortunately, using a dual sensitivity control only partially minimizes the ballooning effect.

[0008] A second method of compensating for the ballooning effect is shown in U.S. Patent No. 5,917,314, entitled "Electronic wall-stud sensor with three capacitive elements," issued June 29, 1999. This second method discloses using three parallel sensing plates and using sums and differences between the various plate capacitances to determine the centerline and edges of a stud.

[0009] The above methods, which use electronic wall stud sensors, are unable to reliably and accurately sense an edge of a stud (or other structural member) through surfaces that are thicker than 38 mm (1 ½ inches). Additionally, these sensors, if overly sensitive, falsely indicate the presence of non-existing studs. Therefore, known sensors have disadvantages.

[0010] US 5917314 describes a device for locating the edges of wall studs including a comparison circuit connected to each of three capacitive elements. As the device is moved along a wall, the comparison circuit monitors the relative charge time associated with each capacitive element, the charge times providing an indication of the relative capacitances of the three capacitive elements. Changes in the relative capacitances of the three elements as the device is moved along a wall are due to a change in the dielectric constant of the wall, which normally results from the presence of a wall stud behind the surface over which the device is moved. The comparison circuit uses differences in the measured relative capacitances of the first, second, and third capacitive elements to locate the edges of the stud.

BRIEF SUMMARY

[0011] An apparatus and method for determining a feature of a member located behind a surface while reducing effects of an unknown thickness of the member are provided. The feature is a centerline of a building object or member, such as a stud or joist but is not so limited. The sensor apparatus includes a plurality of capacitive plates.

[0012] One aspect of the invention provides method of finding a feature behind a surface according to claim 1.

[0013] A second aspect of the invention provides a sensor for finding a feature of a structure according to claim 19.

[0014] The sensor may also include circuitry to sense an effective capacitance created by a plate, the covering and objects behind the covering. The sensor may compute a ratio between the capacitance measurements of a pair of the plates. A ratio of approximately one may indicate a centerline of a stud or joist or similar member. A ratio in a predetermined range may indicate an edge of a stud or joist. Additionally, the sensor may analyze a capacitance measurement to determine a depth of the feature.

[0015] Some embodiments of the invention provide a method of finding a feature behind a surface using a sensor having a first plate and a second plate of approximately equal areas, the method comprising the acts of: moving the sensor and surface adjacent one another; measuring a first capacitance of a first capacitor including the first plate and the feature; measuring a second capacitance of a second capacitor including the second plate and the feature; comparing the first capacitance measurement to the second capacitance measurement; comparing one of the first or second capacitance measurements with a first threshold; and repeating the acts of measuring and comparing.

[0016] Some embodiments of the invention provide a sensor for finding a feature of a structure comprising: a first plate having a first capacitance and adapted for forming a first capacitor with the structure; a second plate having a second capacitance and adapted for forming a second capacitor with the structure; a first measurement circuit coupled to the first plate, the first measurement circuit measuring a first capacitance value of the first capacitor; a second measurement circuit coupled to the second plate, the second measurement circuit measuring a second capacitance value of the second capacitor; and a comparison circuit coupled to the first and second measurement circuits, the comparison circuit generating a ratio of the first and second capacitance values and comparing one of the first or second capacitance values to a first threshold.

[0017] Some embodiments of the invention provide a sensor comprising: a first plate and a second plate positioned in about the same plane and spaced apart, and adapted to be located adjacent a surface; a measurement circuit coupled to the first and second plates thereby to measure a capacitance value of each of the plates; a first comparison circuit coupled to receive the measured capacitance values and determine a ratio between a change in the measured capacitance values; and a second comparison circuit coupled to receive one of the measured capacitance values and a threshold and to provide a comparison therebetween.

[0018] Other features and aspects of the invention will become apparent from the following detailed description, taken in conjunction with the accompanying drawings which illustrate, by way of example, the features in accordance with embodiments of the invention. The summary is not intended to limit the scope of the invention, which is defined solely by the claims attached hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]

FIGURES 1A-1D illustrate a plan view of and capacitance produced by a ratiometric capacitive sensor having two primary plates, in accordance with the present invention, positioned at a lateral distance away from an object, such as a hidden stud.

FIGURES 2A-2C show a sensor centered over studs and a graph of capacitance measurements of two primary plates versus a lateral distance between a sensor and a shallow object and a deep object, such as hidden studs, in accordance with the present invention.

FIGURE 3 illustrates a process to indicate whether or not a depth feature of an object, such as a stud, has been

detected, in accordance with the present invention.

FIGURES 4A and 4B each show a block diagram of a capacitive sensor having two primary plates and circuitry, in accordance with the present invention.

DETAILED DESCRIPTION

[0020] In the following description, reference is made to the accompanying drawings which illustrate several embodiments of the present invention. It is understood that other embodiments may be utilized and mechanical, compositional, structural, electrical, and operational changes may be made without departing from the scope of the present disclosure. The following detailed description is not to be taken in a limiting sense, and the scope of the embodiments of the present invention is defined only by the claims of the issued patent.

[0021] Some portions of the detailed description which follows are presented in terms of procedures, steps, logic blocks, processing, and other symbolic representations of operations on data bits that can be performed on computer memory. A procedure, computer executed step, logic block, process, etc., are here conceived to be a self-consistent sequence of steps or instructions leading to a desired result. The steps are those utilizing physical manipulations of physical quantities. These quantities can take the form of electrical, magnetic, or radio signals capable of being stored, transferred, combined, compared, and otherwise manipulated in a computer system. These signals may be referred to at times as bits, values, elements, symbols, characters, terms, numbers, or the like. Each step may be performed by hardware, software, firmware, or combinations thereof.

[0022] This application relates to U.S. Patent Application No. 10/794,356 filed March 4, 2004, titled "RATIOMETRIC STUD SENSING".

[0023] A ratiometric capacitive sensor may use capacitance measurements from multiple conductive plates to determine the presence of objects, such as studs and joists, hidden behind a covering surface such as a wall, floor, ceiling, etc. In some embodiments, a ratiometric capacitive sensor includes two conductive plates. Each conductive plate acts as part of a separate capacitor. Circuitry coupled to each plate measures an effective change in capacity of the separate capacitors, which is effected by the density of material in close proximity to the plates. As a result, a wall or other surface covering combined with an underlying stud or other member form a larger capacitance than a wall covering alone without a stud. A capacitance measurement may be taken from each plate. The capacitance measurement from one plate may then be compared to a capacitance measurement of another plate to determine boundaries and features of the materials in the vicinity of the plates.

[0024] FIGURE 1A illustrates a plan view of a capacitive sensor 300 having two primary plates 301, 302, in accordance with the present invention. The sensor 300 is positioned against a wall 99 at a lateral distance D away from a hidden stud 100A. A wall may have multiple studs 100 (e.g., 100A, 100B and 100C). Each stud 100 has two edges 102 and defines a centerline 101 relative to its positioning along the wall 99. Additionally, sensor 300 defines a centerline 304 that may be equally positioned between a first plate 301 and a second plate 302. In some embodiments, associated circuitry and/or software (not shown) operates to independently measure values indicative of a capacitance of each plate 301 and 302.

[0025] FIGURES 1B and 1C illustrate a capacitance produced between each respective plate 301 and 302 of the sensor 300 and the wall 99. FIGURE 1B shows a capacitance curve 310 produced by the first plate 301 and the wall 99. FIGURE 1C shows a capacitance curve 320 produced by the second plate 302 and the wall 99. Capacitance curves 310 and 320 are drawn relative to the centerline 304 of the sensor 300. Additionally, curves 310 and 320 show peaks when respective plates 301 and 302 are positioned over the centerline 101 of a stud 100 and show valleys when respective plates 301 and 302 are positioned between pairs of studs 100.

[0026] At points where a sensor 300 measures a minimum capacitance value or a relatively low capacitance value, sensor 300 may be positioned far from any stud 100. The measured capacitance values increase as the sensor 300 nears the stud 100; however, the capacitance values of each plate 301 and 302 will differ if one of the plates is closer to the stud 100. For example, a first plate 301 may be close to or over an edge 102 of a stud 100. At the same time, the second plate 302 may still be positioned at a lateral distance away from the stud 100. In this case, the change in capacitance from its minimum value experienced by the first plate 301 will be greater than the change in capacitance experienced by the second plate 302.

[0027] In some embodiments, the capacitance measurements are used to calculate a ratio. A first capacitance measurement represents the change in capacitance from a calibration value experienced on a first plate 301. A second capacitance measurement represents the change in capacitance from a calibration value experienced on a second plate 302. A ratio between the first and second capacitance measurements may be computed. If the ratio is approximately equal to a determined value, it may be realized that a centerline 304 of the sensor 300 is centered over an edge 102 of a stud 100. If the capacitance measurements are equal or the ratio is approximately equal to unity, both plates may be centered over the stud's edge 102 and the centerline 304 of the sensor 300 may be centered over the centerline 101 of

the stud 100.

[0028] FIGURE ID shows overlapping first and second capacitance curves 310 and 320 relative to the centerline 304 of the sensor 300 and a stud 100. A point at which curves 310 and 320 intersect may indicate a position of the sensor 300 where each plate is encountering an equal capacitance; therefore, the centerline 304 of the sensor 300 may be directly over a centerline 101 of the stud 100. In some embodiments, at least one of the capacitance values must be above a floor threshold value, a value above a calibration capacitance value, before the capacitance measurements are compared with each other.

[0029] FIGURE IE shows a graph of a curve 330, which represents a ratio of capacitance measurements of two primary plates 301, 302 versus a lateral distance between a ratiometric capacitive sensor's centerline 304 and a centerline 101 of a stud 100, in accordance with the present invention. This ratio may be computed as the smaller capacitance divided by the larger capacitance, thereby resulting in a ratio that is equal to or less than one.

[0030] The calculated results, shown in a ratio curve 330, exhibits a sharp peak. The sharp peak of curve 330 allows a ratiometric sensor to locate a stud's centerline 101 with increased accuracy over non-ratiometric sensor, which may generate rounded peaked curves.

[0031] Additionally, a transition ratio may be compared to the calculated ratio to determine the location of an edge 102 of a stud 100 as further described below. The transition ratio predicts a capacitance ratio formed at an edge of a stud when the sensor 300 is centered over the stud's edge for a particular wall structure. As such, a transition ratio may be used to indicate when the sensor 300 is centered over an edge 102.

[0032] A transition ratio may be determined in a number of ways. The transition ratio may be a factory set constant. Alternatively, the transition ratio may be set by an operator. In some embodiments, the transition ratio is calculated during operation.

[0033] In some embodiments, a transition ratio may be set during manufacturing as a factory set constant. For example, a factory may set a transition ratio equal to a fixed value, e.g., 0.33. When plates produce capacitance measurements that form a ratio approximately equal to 0.33, sensor 300 may indicate that the center of sensor 300 is directly over an edge 102 of stud 100.

[0034] In some embodiments, a transition ratio may be directly or indirectly selected by an operator of the sensor. For example, an operator may select a stud width and/or a wall thickness. The stud width and/or wall thickness may be used to select an appropriate transition ratio, for example, as shown in the table below.

Stud Type	Wall Covering Thickness	Transition Ratio
Double stud 76 mm (3 inches)	Single sheet 13 mm ($\frac{1}{2}$ an inch)	0.32
Single stud 38 mm (1 $\frac{1}{2}$ inches)	Single sheet 13 mm ($\frac{1}{2}$ an inch)	0.33
Double stud 76 mm (3 inches)	Double sheet 25 mm (1 inch)	0.35
Single stud 38 mm (1 $\frac{1}{2}$ inches)	Double sheet 25 mm (1 inch)	0.45

[0035] In some embodiments, a transition ratio may be automatically determined by the sensor 300 based on capacitance measurements. A capacitance measurement may be a measure of a maximum capacitance measurement on a plate as shown in FIGURE 3.

[0036] In some circumstances, the actual ratio of measured plate capacitances at the stud's edge 102 varies predictably with the wall thickness. Therefore, a maximum measured capacitance value may be used to set a transition ratio used to locate a stud's edge. This maximum value may indicate a wall covering's thickness, with thicker walls having smaller maximum values. The maximum value may also provide an indication of the width of the stud, with wider studs having larger maximum values. The measured capacitance values may also be compared to indicate a direction of a stud with the plate having a higher capacitance measurement indicating the direction of the center of the stud.

[0037] In some embodiments, plate capacitance is measured by determining a time it takes to charge a plate 301 or 302 to a determined value. In other embodiments, plate capacitance is measured by determining a voltage that charges a plate 301 or 302 within a determined time. In either case, an output of a digital-to-analog converter ("DAC") may provide a voltage used to charge the plate. A DAC output may be represented by a digital input value. An input to the DAC may be supplied from a counter, such as an up/down counter, or may be supplied from a microcontroller or microprocessor. This input value may be referred to as a DAC count. A DAC count may have a determined reference point. For example, a DAC value may be referenced from zero. Alternatively, a DAC value may be referenced from a value determined from calibration processing or the like.

[0038] FIGURES 2A and 2B each illustrate a plan view of capacitive sensor 300 with the centerline 304 centered directly over a centerline 101 of a hidden stud 100, resulting in a center-to-center distance of $D = 0$. In this position, each plate 301 and 302 may be partially over the stud 100. Each plate 301 and 302 will have a capacitance value that is some

minimum threshold above its calibration value, below its maximum value, and approximately equal to a common value. Therefore, a centerline of an object may be located by identifying when two plates have capacitance values equal to a common value that is above some floor threshold value.

[0039] A covering of wall (surface) 99 may be of different thicknesses. A thin wall covering will exhibit a low nominal capacitance, where as a thicker wall covering will exhibit a higher nominal capacitance. A stud positioned behind a thin wall covering will produce a high maximum capacitance. A stud position behind a thicker wall covering will be farther away from the wall's external surface and therefore will produce a lower maximum capacitance.

[0040] FIGURE 2C shows capacitance curves for two plates 301, 302 for a sensor 300 that has been pulled across a wall 99. As a sensor 300 passes over a first stud 100A, sensor 300 measures capacitances shown on curves 310A and 320A for respective plates 301 and 302. As a sensor 300 passes over a second stud 100B, sensor 300 measures lower capacitance values as shown in curves 310B and 320B. Lower capacitance values may represent a deeper (farther behind wall 99) or narrower stud. Alternatively, higher capacitance values may represent a shallower or wider stud.

[0041] Sensor 300 may compare capacitance measurements to a depth threshold. For example, when sensor 300 is positioned over an edge of a stud, a center of a stud, or between edges of a stud, sensor 300 may indicate whether or not the detected stud is a deep stud or not a deep stud. The indication may be an audio indication, such as from a buzzer in sensor 300, a visual indication, such as from an LED, a signal level, such as supplied to a control line, or any combination thereof.

[0042] The indication of a depth of a feature may be used by the sensor operator. For example, if most features are determined to originate from a non-deep stud, the operator may conclude that deep features are anomalies. Similarly, if most features are determined to be deep, then any non-deep features may be ignored by the operator.

[0043] Assuming stud 100A is positioned at a first distance behind a wall's surface and stud 100B is positioned at a farther distance behind the wall's surface, each stud will produce a different capacitance measurement when sensor 300 is centered over the stud. For example, when sensor 300 is centered over stud 100A, DAC counts of 80 above calibration values on each plate may result. When sensor 300 is centered over stud 100B, DAC counts of 30 above the calibration values on each plate may result.

[0044] Plates producing equal measurements above a floor threshold indicate that the sensor is centered over the stud. Additionally, a higher DAC count indicates that the stud is closer to the surface, the stud is wider than a reference stud and surface, or a material of higher conductivity is detected. An example DAC count of 80 may represent that a single-width stud is positioned behind a single-layer of sheetrock. An example DAC count of 30 may represent that a single-width stud is positioned behind a double-layer of sheetrock.

[0045] In some embodiments, a transition ratio may be calculated by sensor 300 based on a historic maximum capacitance measurement. In other embodiments, the transition ratio may be calculated based on an instantaneous maximum capacitance measurement.

[0046] A historic maximum capacitance measurement may be determined over time as measured from either plate 301 or 302. A maximum capacitance measurement is expected when the plate 301 or 302 is centered over a stud. The maximum capacitance measurement may be saved in memory of sensor 300. As the capacitance changes over time, an updated maximum capacitance value may be stored.

[0047] Alternatively, a capacitance measurement may be used. A capacitance measurement may be selected each time the sensor 300 takes each pair of capacitance measurements from plates 301 and 302. In some embodiments, the larger of the two capacitance measurements may represent the capacitance measurement. That is:

$$C = \max\{FirstPlateValue, SecondPlateValue\}.$$

[0048] In other embodiments, the instantaneous capacitance value may be determined by examining the capacitance formed by a single plate 301. In some embodiments, the instantaneous capacitance value is determined over a period of time, e.g., by a moving average or the like.

[0049] Using the capacitance measurement, the sensor 300 may select a transition ratio from a table or compute a transition ratio from a formula. A sensor 300, having plates centered 38 mm (1 ½ inches) apart, with each plate 19 mm (¾ of an inch) wide, may use a transition ratio as shown in the table below. For example, a capacitance measurement of 1.4, representing a double-width stud hidden behind a single sheet of sheetrock, may have a transition ratio of 0.32. A lookup table in the memory of sensor 300 may be used to map a capacitance measurement to a transition ratio.

Capacitance Measurement	Transition Ratio
1.4	0.32
1.0	0.33

(continued)

Capacitance Measurement	Transition Ratio
0.6	0.35
0.4	0.45

[0050] Alternatively, the sensor 300 may compute a transition ratio for each ratio calculation. In some embodiments, a transition ratio may be calculated as:

$$TR(P) = \begin{cases} 0.61 - 0.28 \frac{C}{P_{1/2}} & \text{if } C < P_{1/2} \\ 0.33 & \text{else} \end{cases}$$

where $TR(P)$ is a Transition Ratio; $P_{1/2}$ is a design constant; and C is a Capacitance Measurement. The design constant $P_{1/2}$ may be set during manufacturing and may represent the expected maximum capacitance measured over a reference wall structure having a single (nominal) stud having a width of 44 mm (1 3/4 inches) and a wall covering 99 having a thickness of 13 mm (1/2 of an inch). In some embodiments, the capacitance C parameter may be the historical maximum capacitance. In other embodiments, the capacitance C parameter may be the instantaneous maximum capacitance of two plate measurements as described above. The formula shows that if C is less than the design constant $P_{1/2}$, the formula is used. If C is greater than or equal to the design constant $P_{1/2}$, a fix value of 0.33 is used.

[0051] Once determined, the transition ratio may be used to indicate whether the sensor is centered over an edge of a stud. Sensor 300 may measure a first capacitance value on a first plate 301 and a second capacitance value on a second plate 302. A capacitance ratio may be calculated between the first and second capacitance values. This capacitance ratio may be compared to the predicted transition ratio to determine whether the sensor 300 is presently centered over an edge 102 of a stud 100.

[0052] For example, sensor 300 measuring a larger capacitance value of 1.4 may indicate the sensor 300 has passed over a double-wide stud having a width of 76 mm (3 inches) hidden behind a single layer of sheetrock having a thickness of 13 mm (1/2 an inch). The transition ratio for this wall structure may be set to a value of 0.32. When the sensor 300 detects a position where the first and second capacitance measurements are approximately equal to 0.32, the sensor 300 may indicate that the sensor 300 is centered over an edge 102. In some embodiments, the stud's edge location may be determined to an accuracy of approximately 3 mm (1/8 of an inch) over a wall covering thickness range of 13 to 25 mm (1/2 to 1 inch).

[0053] Measured capacitance values indicate a direction in which a stud 100 is located. At a stud's edge 102, one plate may be directly over the centerline 101 of the stud 100, while the other may be off to one side of the stud 100. The plate 301 or 302 positioned over the stud 100 will have a larger capacitance than the other plate 302 or 301 and will pass through a maximum value as the sensor 300 is drawn across the stud 100. A plate 301 or 302 showing a larger capacitance indicates that the centerline 304 of the sensor 300 needs to be moved in the direction of that plate 301 or 302.

[0054] A ratio curve 330 may be computed as follows. When the first plate 301 produces a capacitance that is greater than the capacitance produced by the second plate 302, a ratio is calculated by dividing the second plate's change in capacitance value by the larger first plate's change in capacitance value. Similarly, when the first plate 301 produces a capacitance that is less than the capacitance produced by the second plate 302, the ratio is calculated by dividing the smaller first plate's change in capacitance value by the second plate's change in capacitance value. Formulaically, the ratio curve 330 may be computed by:

$$cap_ratio(D) = \frac{\min\{FirstPlateValue(D), SecondPlateValue(D)\}}{\max\{FirstPlateValue(D), SecondPlateValue(D)\}}$$

where the plate value may be a change in value from a calibration value such as a nominal or minimal value determined during calibration. Theoretically, a plate value may be an absolute measurement of capacitance rather than a measurement of a change in capacitance. Practically, a plate value or capacitance measurement is a relative measurement from a value that may exclude parasitic capacitances of a sensor's circuitry and a wall covering. In some embodiments, a plate value is an indirect measure of capacitance. For example, the plate value may be a measure of a number of clock

cycles necessary to charge a plate 301 or 302 to a reference level.

[0055] FIGURE 3 illustrates a process to indicate whether or not a depth feature of an object has been detected, in accordance with the present invention as carried out by a computer program executed by a processor resident in the sensor. The order of steps presented may be rearranged by those of ordinary skill in the art and coding such a program is well within the skill of one of ordinary skill in the art in light of this disclosure. Further, the steps of this process may conventionally be undertaken by conventional circuitry or the computer program or by a combination thereof.

[0056] At step 700, a sensor 300 powers up and maybe positioned against a surface 99. Sensor 300 performs a calibration step 710 to reduce the impact of parasitic circuit and wall capacitances. The calibration step determines a calibration capacitance such as a DAC value that represents an absolute capacitance of a plate over the wall structure and includes parasitic capacitances of the sensor 300.

[0057] At step 720, sensor 300 begins a process of measuring plate capacitances, e.g., determining capacitance measurements in the form of a relative capacitance values from the calibration capacitance values. At step 730, the sensor 300 computes a capacitance ratio between plate capacitance measurements from step 720.

[0058] At step 740, a sensor 300 determines whether the capacitive measurements of step 720 indicate a centerline 101 of an object or a discontinuity has been detected. That is, if the capacitance ratio is approximately equal to unity, or alternatively, if the capacitance measurements are approximately equal to one another. If not, the process may continue to step 770. If so, at step 750, sensor 300 may provide a visual and/or an audio indication that a centerline 101 of the object or the discontinuity is detected.

[0059] At step 760, sensor 300 determines whether the detected center is a deep feature. A deep feature may be determined by comparing one or more of the measured plate capacitances (from step 720) with a threshold value such as depth threshold indicated in FIGURE 2C. If a deep feature is not detected, sensor 300 repeats the process with step 720. If a deep feature is detected, at step 765, sensor 300 may provide an indication that a deep feature was detected.

[0060] At step 770, sensor 300 determines a transition ratio. At step 780, sensor 300 compares the computed capacitance ratio to the determined transition ratio. That is, sensor 300 determines whether the capacitive measurements of step 720 indicate that an edge of an object or a discontinuity has been detected. An edge is detected when the capacitance ratio is approximately equal to a transition ratio. If not, sensor 300 repeats the process with step 720. If so, at step 790, sensor 300 provides a visual and/or an audio indication that an edge of the object or the discontinuity is detected. A sensor 300 then determines whether the detected edge is a deep feature as described with step 760 above.

[0061] Additionally, sensor 300 may determine a relative direction an object or a discontinuity exists based on the relative magnitudes of the measured plate capacitances. For example, the sensor 300 indicates that the stud is positioned to the left of the centerline 304 of the sensor 300. Sensor 300 indicates the direction of an object or a discontinuity audibly and/or visually.

[0062] In operation, an operator or user may pass sensor 300 across wall 99. If each stud feature is detected as not being associated with a deep stud except for one stud, the operator may use the deep indication as a warning and conclude the deep feature is an anomaly.

[0063] Similarly, if an operator discovers all stud features are associated with deep studs except for one non-deep stud, the operator may conclude that the non-deep stud is an anomaly. For example, a wall may have all wood studs and some metallic wiring. The wood studs, if behind two or three layers of sheetrock, may appear as deep studs. The metal wiring may appear as a shallow stud. The operator may conclude that the indication of a shallow stud was erroneous.

[0064] An apparatus in accordance with the present invention may have features implemented in hardware, software or a combination of hardware and software. Thus, blocks described with reference to the following figures may be implemented in hardware, software, firmware, dedicated circuitry, and/or programmable circuitry, or a combination thereof.

[0065] FIGURE 4A shows a block diagram of a capacitive sensor having two primary plates 301 and 302 and associated circuitry 400A, in accordance with the present invention. In some embodiments, a sensor includes a first plate 301, a second plate 302 and electronic circuitry 400A having a first measurement circuit 410A, a second measurement circuit 410B, a comparison circuit 414, and an indicator 416. The first and second plates 301 and 302 are conventionally charged and discharged by the respective first and second measurement circuits 410A, 410B.

[0066] Each measurement circuit 410A, 410B provides a capacitance measurement to the comparison circuit 414. The capacitance measurement may be an indication of a change in capacitance from a nominal capacitance experienced during calibration. The comparison circuit 414 processes the capacitance measurements. For example, the comparison circuit 414 may compute a ratio between the capacitive measurements. The comparison circuit 414 may determine whether the capacitive measurements are within a predetermined value of each other. The comparison circuit 414 may determine whether one of the capacitive measurements is above or below a threshold, thereby determining a depth feature of an object, e.g., whether the object, such as a stud, is far or near to the surface.

[0067] The comparison circuit 414 then provides a signal to the indicator 416. The indicator 416 may be used to alert the operator of information regarding an object, such as a stud. The indicator 416 may identify a detection of, for example, an edge of an object, a center of an object, or that the sensor is over an object, or the sensor is approaching an object.

The indicator 416 may provide a direction of increasing capacitance, thereby informing an operator as to which direction to move the sensor. The indicator 416 may also provide an indication of whether the object is near or far/deep from the surface. The comparison circuit 414 (e.g., a comparator) may compare and/or process the capacitance measurements to determine whether an object or a discontinuity is present and/or whether a feature of an object or a discontinuity is detected. For example, comparison circuit 414 may determine that the sensor 300 is centered over a stud 100 by detecting that the capacitance measurements are equal to each other and also above a floor threshold. Capacitance measurements may be considered equal when they are within a predetermined percentage value or absolute value from each other.

[0068] Comparison circuit 414 may determine that the sensor is centered over an edge 102 of a stud 100 by detecting that the capacitance measurements form a ratio that is equal to a transition ratio. The transition ratio may be a fixed value, a value indirectly or directly selected by a user, a value extracted from a lookup table or a computed value. A capacitance ratio may be considered equal to the transition ratio when the capacitance ratio falls within range of values about the transition ratio.

[0069] In some embodiments, the comparison circuit 414 couples capacitance measurement to the indicator 416. The indicator 416 may visually (or audibly) display a value indicative of each capacitance value. The operator may use the displayed values to visually determine whether an object or a discontinuity exists, for example, by looking for changing capacitive measurements. Additionally, an operator may use the displayed values to visually determine the location of edges 102 and centerlines 101 of studs 100, for example, by looking for capacitance measurements equaling a transition ratio.

[0070] FIGURE 4B shows another version of a sensor having two primary plates 301 and 302 and circuitry 400B. The sensor includes a first plate 301, a second plate 302 and electronic circuitry 400B having a first measurement circuit 420A, a second measurement circuit 420B, a properly programmed microcomputer or a microcontroller 424, and an indicator 426. Here microcontroller 424 carries out the comparator functions of comparison circuit 414 of FIGURE 4A.

[0071] The first and second plates 301 and 302 are charged and discharged by the respective first and second measurement circuits 420A, 420B. Each measurement 402A, 402B circuit provides a capacitance measurement to the microcontroller 424. Additionally, the microcontroller 424 may provide timing or other control signals to the first and second measurement circuits 420A and 420B. The microcontroller 424 processes the capacitance measurements and may provide a signal to the indicator 426. The indicator 416 may include a display, such as a liquid crystal display and/or LEDs, and may include an audio device, such as a speaker or buzzer.

[0072] A ratiometric capacitive sensor 300 in accordance with the invention may be used to detect a variety of hidden objects in addition to studs and joists. For example, a sensor having long and narrow plates may be used to find a crack or gap hidden behind a surface. Sensor 300 may be used to find a safe hidden behind a wall. Sensor 300 may be used to find brick wall hidden behind sheetrock. Additionally, sensor 300 may be stationary and be positioned to allow objects with hidden features to pass across its plates.

[0073] While the present invention has been described with reference to one or more particular variations, those skilled in the art will recognize that many changes may be made thereto without departing from the scope of the present invention. Each of these embodiments and obvious variations thereof are contemplated as falling within the scope of the claimed invention, which is set forth in the following claims.

Claims

1. A method of finding a feature (100) behind a surface (99) using a sensor (300) having first and second plates (301, 302), the method comprising the acts of:

moving the sensor (300) and surface (99) adjacent one another;
measuring (720) a first capacitance of a first capacitor including the first plate (301) and the feature (100);
measuring (720) a second capacitance of a second capacitor including the second plate (302) and the feature (100); **characterized by**

computing (730) a ratio of the first and second capacitance measurements to determine a centerline of the feature (100) relative to the first and second plates (301; 302); and
comparing one of the first or second capacitance measurements with a first threshold, thereby to determine a depth of the feature (100) relative to the surface (99), wherein the act of comparing one of the first or second capacitance measurements with the first threshold includes:

determining a largest capacitance measurement of the first or second capacitance measurements; and
determining (765) the feature (100) is deep if the largest capacitance measurement is less than the first threshold.

2. A method according to claim 1, further comprising repeating the acts of measuring and comparing.
3. The method of claim 1, further comprising the act of determining whether the ratio is within a predetermined range, indicating that an edge (102) of an object behind the surface (99) is detected.
- 5 4. The method of any one of claims 1 to 3, further comprising the acts of:

determining a first reference that represents an initial capacitance of the first capacitor; and
10 determining a second reference that represents an initial capacitance of the second capacitor.
5. The method of claim 4, wherein:

the first capacitance measurement is a difference between the first reference and the first capacitance measurement; and
15 the second capacitance measurement is a difference between the second reference and the second capacitance measurement.
6. The method of any one of claims 1 to 5, further comprising the acts of:

20 determining whether one or more of the first and second capacitance measurements is greater than or equal to the first threshold; and
repeating measurement of the first and second capacitances if one or more of the first and second capacitance measurements is greater than or equal to the first threshold.
- 25 7. The method of claim 3, wherein a denominator of the ratio is a maximum of the first and second capacitance measurements.
8. The method of claim 3, wherein the predetermined range is a range having fixed limits.
- 30 9. The method of claim 1, further including indicating the feature (100) is deep if the one of the first or second capacitance measurements is less than the first threshold.
10. The method of claim 1, further including indicating the feature is not deep if the one of the first or second capacitance measurements is greater than the first threshold.
- 35 11. The method of claim 1, further comprising the acts of:

comparing the first and second capacitance measurements;
40 determining that an edge (102) of an object behind the surface (99) is closer to a centerline (304) of the first plate (301) than a centerline of the second plate if the first capacitance measurement is greater than the second capacitance measurement; and
determining that the edge (102) is closer to the centerline of the second plate (302) than the centerline of the first plate (301) if the first capacitance measurement is less than the second capacitance measurement.
- 45 12. The method of any one of the preceding claims, further comprising the acts of determining whether the ratio is within a predetermined range of a value of one, and if so indicating that the centerline (101) is detected.
13. The method of claim 12, wherein the predetermined range is inclusively 0.9 to 1.
- 50 14. The method of any one of the preceding claims, wherein the first and second capacitances are indicative of a duration of time necessary to charge a respective one of the first and second plates (301, 302) to a respective reference level.
15. The method of claim 4, wherein:

55 the first reference is indicative of a duration of time necessary to charge the first plate (301) having the initial capacitance to a first reference;
the second reference is indicative of a duration of time necessary to charge the second plate (302) having the initial capacitance to a second reference;

wherein the first capacitance is a difference between the first reference and a duration of time to charge the first plate (301) to the first reference; and
 the second capacitance is a difference between the second reference and a duration of time to charge the second plate (302) to the second reference.

5 16. The method of claim 4, wherein:

the first reference is indicative of a first voltage necessary to charge the first plate (301) having the initial capacitance to a first reference within a determined time;
 10 the second reference is indicative of a second voltage necessary to charge the second plate (302) having the initial capacitance to a second reference within the determined time;
 wherein the first capacitance measurement is a difference between the first reference and an indication of the first voltage; and
 wherein the second capacitance measurement is a difference between the second reference and an indication
 15 of the second voltage.

17. The method of any one of the preceding claims, the act of moving comprising applying the sensor (300) to the surface (99), or applying the surface (99) to the sensor (300).

20 18. The method of any one of the preceding claims, wherein the act of comparing the first and second capacitance measurements includes:

determining whether the first and second capacitance measurements are equal;
 indicating that, if the first and second capacitances are equal, the centerline (101) is detected.

25 19. A sensor (300) for finding a feature (100) behind a surface (99), comprising:

a first plate (301) having a first capacitance and adapted for forming a first capacitor with the structure;
 a second plate (302) having a second capacitance and adapted for forming a second capacitor with the structure;
 30 a first measurement circuit (410A) coupled to the first measurement circuit (410A) measuring a first capacitance value of the first capacitor;
 a second measurement circuit (410B) coupled to the second plate (302), the second measurement (410B) circuit measuring a second capacitance value of the second capacitor;
 a comparison circuit (414) coupled to the first and second measurement circuits (410A; 410B), **characterized**
 35 **by** the comparison circuit (414) generating a ratio of the first and second capacitance values to determine a centerline of the feature (100) relative to the first and second plates (301, 302) and comparing one of the first or second capacitance values to a first threshold to determine a depth of the feature (100) relative to the surface (99);
 threshold circuitry coupled to first and second measurement circuits (410A; 410B) and configured for determining
 40 whether the first and second capacitance values are below the first threshold to determine (760) if the feature (100) is deep.

20. The sensor according to claim 19, wherein the first plate (301) and the second plate (302) are positioned in about the same plane and spaced apart and adapted to be located adjacent a surface (99), the comparison circuit (414)
 45 configured to:

determine a change in the measured capacitance values;
 compute a ratio between the change in the measured capacitance values; and
 compare the measured capacitance values with the first threshold.

50 21. The sensor of claim 19 or 20, wherein:

the first capacitance value represents a difference between the first capacitance and an initial capacitance of the first capacitor; and
 55 the second capacitance value represents a difference between the second capacitance and an initial capacitance of the second capacitor.

22. The sensor of claim 19, wherein the comparison circuit further determines whether the first and second capacitance

values are greater than or equal the first threshold to determine if the feature is not deep.

23. The sensor of claim 19, further comprising a processing circuit coupled to the comparison circuit (414) and coupled to receive the ratio value, and to determine whether the ratio is within a predetermined range.

24. The sensor of claim 23, further comprising an indicator (416) coupled to the comparison circuit (414) thereby to provide an indication of the ratio of the capacitances.

25. The sensor of claim 23, wherein the indicator (416) is adapted to provide an indication that the sensor (300) is over an edge (102) of the structure when the ratio is within the predetermined range.

26. The sensor of claim 23, wherein the indicator (416) is adapted to provide an indication that the sensor (300) is over a centerline (101) of a portion of the structure when the ratio is within the range of one.

27. The sensor of claim 20, further comprising an indicator coupled to the second comparison circuit thereby to provide an indication of a depth of a feature behind the surface (99).

28. The sensor of claim 25, further including a memory storing look-up table and coupled to the processing circuit, the look-up table having a transition ratio for the processing circuit, wherein the transition ratio is used to set the predetermined range.

29. The sensor of claim 23, further comprising:

a source of a reference voltage;

wherein the first measurement circuit includes a first index, the first index indicating a number of clock cycles needed to charge the first plate (301) to the reference voltage level; and

wherein the second measurement circuit includes a second index, the second index indicating a number of clock cycles needed to charge the second plate (302) to the reference voltage level.

30. The sensor of claim 29, wherein the first and second measurement circuits respectively include:

a current source coupled to a respective one of the first or second plates (301, 302);

a discharge switch coupled to the respective one of the first or second plates (301, 302);

a digital-to-analog converter (DAC) having an input terminal coupled to receive a data signal from the processing circuit and an output terminal; and

a comparator having a first input terminal coupled to the respective one of the first or second plates (301, 302), a second input terminal coupled to the DAC, and an output terminal providing the output signal of the measurement circuit.

Patentansprüche

1. Verfahren zum Finden eines Merkmals (100) unter einer Oberfläche (99) mithilfe eines Sensors (300) mit einer ersten und einer zweiten Platte (301, 302), wobei das Verfahren folgende Schritte umfasst:

Bewegen des Sensors (300) und der Oberfläche (99) nebeneinander,

Messen (720) einer ersten Kapazität eines ersten Kondensators einschließlich der ersten Platte (301) und des Merkmals (100),

Messen (720) einer zweiten Kapazität eines zweiten Kondensators einschließlich der zweiten Platte (302) und des Merkmals (100),

gekennzeichnet durch

das Berechnen (730) eines Verhältnisses des ersten und des zweiten Kapazitätsmesswerts zum Bestimmen einer Mittellinie des Merkmals (100) in Bezug zu der ersten und der zweiten Platte (301; 302) und

Vergleichen des ersten oder des zweiten Kapazitätsmesswerts mit einem ersten Schwellenwert, um dadurch eine Tiefe des Merkmals (100) in Bezug zur Oberfläche (99) zu bestimmen, wobei das Vergleichen des ersten oder des zweiten Kapazitätsmesswerts mit dem ersten Schwellenwert Folgendes umfasst:

Bestimmen eines größten Kapazitätsmesswerts unter dem ersten und dem zweiten Kapazitätsmesswert

und

Bestimmen (765), dass das Merkmal (100) tief liegt, wenn der größte Kapazitätsmesswert unter dem ersten Schwellenwert liegt.

- 5 **2.** Verfahren nach Anspruch 1, das ferner das Wiederholen des Messens und des Vergleichens umfasst.
- 3.** Verfahren nach Anspruch 1, das ferner das Bestimmen umfasst, ob das Verhältnis in einem vorgegebenen Bereich liegt, was angibt, dass eine Kante (102) eines Gegenstands unter der Oberfläche (99) erkannt wird.
- 10 **4.** Verfahren nach einem der Ansprüche 1 bis 3, das ferner folgende Schritte umfasst:

 Bestimmen eines ersten Bezugswerts, der eine Anfangskapazität des ersten Kondensators darstellt, und
 Bestimmen eines zweiten Bezugswerts, der eine Anfangskapazität des zweiten Kondensators darstellt.
- 15 **5.** Verfahren nach Anspruch 4, wobei:

 es sich bei dem ersten Kapazitätsmesswert um eine Differenz zwischen dem ersten Bezugswert und dem ersten Kapazitätsmesswert handelt und
 bei dem zweiten Kapazitätsmesswert um eine Differenz zwischen dem zweiten Bezugswert und dem zweiten Kapazitätsmesswert handelt.
- 20 **6.** Verfahren nach einem der Ansprüche 1 bis 5, das ferner folgende Schritte umfasst:

 Bestimmen, ob der erste oder/und der zweite Kapazitätsmesswert größer gleich dem ersten Schwellenwert ist
25 und
 Wiederholen der Messung der ersten und der zweiten Kapazität, wenn der erste oder/und der zweite Kapazitätsmesswert größer gleich dem ersten Schwellenwert ist.
- 30 **7.** Verfahren nach Anspruch 3, wobei ein Nenner des Verhältnisses ein Maximalwert des ersten und des zweiten Kapazitätsmesswerts ist.
- 8.** Verfahren nach Anspruch 3, wobei es sich bei dem vorgegebenen Bereich um einen Bereich mit festen Grenzen handelt.
- 35 **9.** Verfahren nach Anspruch 1, das ferner das Anzeigen umfasst, dass das Merkmal (100) tief liegt, wenn der erste oder der zweite Kapazitätsmesswert unter dem ersten Schwellenwert liegt.
- 10.** Verfahren nach Anspruch 1, das ferner das Anzeigen umfasst, dass das Merkmal nicht tief liegt, wenn der erste oder der zweite Kapazitätsmesswert über dem ersten Schwellenwert liegt.
- 40 **11.** Verfahren nach Anspruch 1, das ferner folgende Schritte umfasst:

 Vergleichen des ersten und des zweiten Kapazitätsmesswerts,
 Bestimmen, dass eine Kante (102) eines Gegenstands unter der Oberfläche (99) näher an einer Mittellinie (304) der ersten Platte (301) als an einer Mittellinie der zweiten Platte liegt, wenn der erste Kapazitätsmesswert größer ist als der zweite Kapazitätsmesswert, und
45 Bestimmen, dass die Kante (102) näher an der Mittellinie der zweiten Platte (302) als an der Mittellinie der ersten Platte (301) liegt, wenn der erste Kapazitätsmesswert kleiner ist als der zweite Kapazitätsmesswert.
- 50 **12.** Verfahren nach einem der vorhergehenden Ansprüche, das ferner das Bestimmen, ob das Verhältnis in einem vorgegebenen Bereich eines Werts eins liegt, und, wenn dies der Fall ist, das Anzeigen umfasst, dass die Mittellinie (101) erkannt wird.
- 55 **13.** Verfahren nach Anspruch 12, wobei der vorgegebene Bereich bei 0,9 bis einschließlich 1 liegt.
- 14.** Verfahren nach einem der vorhergehenden Ansprüche, wobei die erste und die zweite Kapazität einen Zeitraum angeben, der zum Laden der ersten beziehungsweise der zweiten Platte (301, 302) auf einen jeweiligen Bezugspegel erforderlich ist.

15. Verfahren nach Anspruch 4, wobei:

der erste Bezugswert einen Zeitraum angibt, der zum Laden der ersten Platte (301) mit der Ausgangskapazität auf einen ersten Bezugswert erforderlich ist,
 der zweite Bezugswert einen Zeitraum angibt, der zum Laden der zweiten Platte (302) mit der Ausgangskapazität auf einen zweiten Bezugswert erforderlich ist,
 wobei es sich bei der ersten Kapazität um eine Differenz zwischen dem ersten Bezugswert und einem Zeitraum zum Laden der ersten Platte (301) auf den ersten Bezugswert handelt und
 wobei es sich bei der zweiten Kapazität um eine Differenz zwischen dem zweiten Bezugswert und einem Zeitraum zum Laden der zweiten Platte (302) auf den zweiten Bezugswert handelt.

16. Verfahren nach Anspruch 4, wobei:

der erste Bezugswert eine erste Spannung angibt, die zum Laden der ersten Platte (301) mit der Ausgangskapazität innerhalb einer vorgegebenen Zeit auf einen ersten Bezugswert erforderlich ist,
 der zweite Bezugswert eine zweite Spannung angibt, die zum Laden der zweiten Platte (302) mit der Ausgangskapazität innerhalb der vorgegebenen Zeit auf einen zweiten Bezugswert erforderlich ist,
 wobei es sich bei dem ersten Kapazitätsmesswert um eine Differenz zwischen dem ersten Bezugswert und einer Angabe zur ersten Spannung handelt und
 wobei es sich bei dem zweiten Kapazitätsmesswert um eine Differenz zwischen dem zweiten Bezugswert und einer Angabe zur zweiten Spannung handelt.

17. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Bewegen des Anlegen des Sensors (300) an die Oberfläche (99) oder das Anlegen der Oberfläche (99) an den Sensor (300) umfasst.

18. Verfahren nach einem der vorhergehenden Ansprüche, wobei das Vergleichen des ersten und des zweiten Kapazitätsmesswerts Folgendes umfasst:

Bestimmen, ob der erste und der zweite Kapazitätsmesswert gleich sind, Angeben, dass die Mittellinie (101) erkannt wird, wenn die erste und die zweite Kapazität gleich sind.

19. Sensor (300) zum Finden eines Merkmals (100) unter einer Oberfläche (99), der Folgendes umfasst:

eine erste Platte (301) mit einer ersten Kapazität, die zum Bilden eines ersten Kondensators mit der Konstruktion ausgelegt ist,
 eine zweite Platte (302) mit einer zweiten Kapazität, die zum Bilden eines zweiten Kondensators mit der Konstruktion ausgelegt ist,
 eine erste Messschaltung (410A), die mit der ersten Messschaltung (410A) gekoppelt ist und einen ersten Kapazitätswert des ersten Kondensators misst,
 eine zweite Messschaltung (410B), die mit der zweiten Platte (302) gekoppelt ist, wobei die zweite Messschaltung (410B) einen zweiten Kapazitätswert des zweiten Kondensators misst,
 eine Vergleichsschaltung (414), die mit der ersten und der zweiten Messschaltung (410A; 410B) gekoppelt ist, **dadurch gekennzeichnet, dass** die Vergleichsschaltung (414) ein Verhältnis des ersten und des zweiten Kapazitätswerts erzeugt und so eine Mittellinie des Merkmals (100) in Bezug zu der ersten und der zweiten Platte (301, 302) bestimmt und den ersten oder den zweiten Kapazitätswert mit einem Schwellenwert vergleicht und so eine Tiefe des Merkmals (100) in Bezug zur Oberfläche (99) bestimmt,
 Schwellenwertschaltungen, die mit einer ersten und einer zweiten Messschaltung (410A; 410B) gekoppelt und zum Bestimmen konfiguriert sind, ob der erste und der zweite Kapazitätswert unter dem ersten Schwellenwert liegen, um zu bestimmen (760), ob das Merkmal (100) tief liegt.

20. Sensor nach Anspruch 19, wobei die erste Platte (301) und die zweite Platte (302) in etwa in der gleichen Ebene angeordnet und voneinander beabstandet und so ausgelegt sind, dass sie sich an eine Oberfläche (99) anlegen lassen, wobei die Vergleichsschaltung (414) so konfiguriert ist, dass sie:

eine Änderung der gemessenen Kapazitätswerte bestimmt,
 ein Verhältnis zwischen der Änderung bei den gemessenen Kapazitätswerten berechnet und
 die gemessenen Kapazitätswerte mit dem ersten Schwellenwert vergleicht.

21. Sensor nach Anspruch 19 oder 20, wobei:

der erste Kapazitätswert eine Differenz zwischen der ersten Kapazität und einer Anfangskapazität des ersten Kondensators darstellt und
 der zweite Kapazitätswert eine Differenz zwischen der zweiten Kapazität und einer Anfangskapazität des zweiten Kondensators darstellt.

22. Sensor nach Anspruch 19, wobei die Vergleichsschaltung ferner bestimmt, ob der erste und der zweite Kapazitätswert größer gleich dem ersten Schwellenwert sind, um zu bestimmen, ob das Merkmal nicht tief liegt.

23. Sensor nach Anspruch 19, der ferner eine Verarbeitungsschaltung umfasst, die mit der Vergleichsschaltung (414) sowie so gekoppelt ist, dass sie den Verhältniswert empfängt und bestimmt, ob das Verhältnis in einem vorgegebenen Bereich liegt.

24. Sensor nach Anspruch 23, der ferner einen Indikator (416) umfasst, der mit der Vergleichsschaltung (414) gekoppelt ist und dadurch eine Angabe zum Verhältnis der Kapazitäten liefert.

25. Sensor nach Anspruch 23, wobei der Indikator (416) so ausgelegt ist, dass er eine Angabe dazu liefert, dass sich der Sensor (300) über einer Kante (102) der Konstruktion befindet, wenn das Verhältnis im vorgegebenen Bereich liegt.

26. Sensor nach Anspruch 23, wobei der Indikator (416) so ausgelegt ist, dass er eine Angabe dazu liefert, dass sich der Sensor (300) über einer Mittellinie (101) eines Teils der Konstruktion befindet, wenn das Verhältnis im Bereich von eins liegt.

27. Sensor nach Anspruch 20, der ferner einen Indikator umfasst, der mit der zweiten Vergleichsschaltung gekoppelt ist und dadurch eine Angabe zu einer Tiefe eines Merkmals unter der Oberfläche (99) liefert.

28. Sensor nach Anspruch 25, der ferner einen Speicher aufweist, der eine Nachschlagetabelle speichert und mit der Verarbeitungsschaltung gekoppelt ist, wobei die Nachschlagetabelle ein Übergangsverhältnis für die Verarbeitungsschaltung aufweist, wobei das Übergangsverhältnis zum Einstellen des vorgegebenen Bereichs verwendet wird.

29. Sensor nach Anspruch 23, der ferner Folgendes umfasst:

eine Quelle für eine Bezugsspannung,
 wobei die erste Messschaltung einen ersten Index aufweist, der eine Anzahl Taktzyklen angibt, die zum Laden der ersten Platte (301) auf den Bezugsspannungspegel erforderlich sind, und
 wobei die zweite Messschaltung einen zweiten Index aufweist, der eine Anzahl Taktzyklen angibt, die zum Laden der zweiten Platte (302) auf den Bezugsspannungspegel erforderlich sind.

30. Sensor nach Anspruch 29, wobei die erste und die zweite Messschaltung jeweils Folgendes aufweist:

eine Stromquelle, die jeweils mit der ersten oder der zweiten Platte (301, 302) gekoppelt ist,
 einen Entladeschalter, der jeweils mit der ersten oder der zweiten Platte (301, 302) gekoppelt ist,
 einen Digital-Analog-Wandler (DAW) mit einer Eingangsklemme, die so gekoppelt ist, dass sie ein Datensignal aus der Verarbeitungsschaltung empfängt, und einer Ausgangsklemme und
 einen Komparator mit einer ersten Eingangsklemme, die jeweils mit der ersten oder der zweiten Platte (301, 302) gekoppelt ist, einer zweiten Eingangsklemme, die mit dem DAW gekoppelt ist, und einer Ausgangsklemme, die das Ausgangssignal der Messschaltung liefert.

Revendications

1. Procédé de détection d'une caractéristique (100) derrière une surface (99) au moyen d'un capteur (300) ayant des première et seconde plaques (301, 302), le procédé comprenant les actions consistant à :

déplacer le capteur (300) et une surface (99) mutuellement adjacents ;
 mesurer (720) une première capacité d'un premier condensateur incluant la première plaque (301) et la caractéristique (100) ;
 mesurer (720) une seconde capacité d'un second condensateur incluant la seconde plaque (302) et la caractéristique (100) ;

téristique (100) ;

le procédé étant **caractérisé par** les actions consistant à :

5 calculer (730) un rapport entre les première et seconde mesures de capacité pour déterminer une ligne médiane de la caractéristique (100) par rapport aux première et seconde plaques (301, 302) ; et comparer une des première et seconde mesures de capacité à un premier seuil, de manière à déterminer une profondeur de la caractéristique (100) par rapport à la surface (99), l'action de comparaison d'une des première et seconde mesures de capacité au premier seuil comprenant les actions consistant à :

10 déterminer une mesure de capacité maximale des première et seconde mesures de capacité ; et déterminer (765) que la caractéristique (100) est profonde si la mesure de capacité maximale est inférieure au premier seuil.

15 2. Procédé selon la revendication 1, comprenant en outre la répétition des actions de mesure et de comparaison.

3. Procédé selon la revendication 1, comprenant en outre l'action consistant à déterminer si le rapport est dans un intervalle prédéterminé, indiquant qu'un bord (102) d'un objet derrière la surface (99) est détecté.

20 4. Procédé selon l'une quelconque des revendications 1 à 3, comprenant en outre les actions consistant à :

déterminer une première référence qui représente une capacité initiale du premier condensateur ; et déterminer une seconde référence qui représente une capacité initiale du second condensateur.

25 5. Procédé selon la revendication 4, dans lequel :

la première mesure de capacité est une différence entre la première référence et la première mesure de capacité ; et la seconde mesure de capacité est une différence entre la seconde référence et la seconde mesure de capacité.

30 6. Procédé selon l'une quelconque des revendications 1 à 5, comprenant en outre les actions consistant à :

déterminer si une ou plusieurs des première et seconde mesures de capacité sont supérieures ou égales au premier seuil ; et répéter une mesure des première et seconde capacités si une ou plusieurs des première et seconde mesures de capacité sont supérieures ou égales au premier seuil.

35 7. Procédé selon la revendication 3, dans lequel un dénominateur du rapport est un maximum des première et seconde mesures de capacité.

40 8. Procédé selon la revendication 3, dans lequel l'intervalle prédéterminé est un intervalle ayant des limites fixes.

9. Procédé selon la revendication 1, comprenant en outre l'action consistant à indiquer que la caractéristique (100) est profonde si ladite mesure parmi les première et seconde mesures de capacité est inférieure au premier seuil.

45 10. Procédé selon la revendication 1, comprenant en outre l'action consistant à indiquer que la caractéristique n'est pas profonde si ladite mesure parmi les première et seconde mesures de capacité est supérieure au premier seuil.

11. Procédé selon la revendication 1, comprenant en outre les actions consistant à :

50 comparer les première et seconde mesures de capacité ; déterminer qu'un bord (102) d'un objet derrière la surface (99) est plus proche d'une ligne médiane (304) de la première plaque (301) que d'une ligne médiane de la seconde plaque si la première mesure de capacité est supérieure à la seconde mesure de capacité ; et déterminer que le bord (102) est plus proche de la ligne médiane de la seconde plaque (302) que de la ligne médiane de la première plaque (301) si la première mesure de capacité est inférieure à la seconde mesure de capacité.

55 12. Procédé selon l'une quelconque des revendications précédentes, comprenant en outre les actions consistant à

déterminer si le rapport est dans un intervalle prédéterminé d'une valeur égale à un, et dans ce cas, indiquer que la ligne médiane (101) est détectée.

13. Procédé selon la revendication 12, dans lequel l'intervalle prédéterminé va de 0,9 à 1 inclus.

14. Procédé selon l'une quelconque des revendications précédentes, dans lequel les première et seconde capacités sont représentatives d'une durée de temps nécessaire pour charger une plaque respective des première et seconde plaques (301, 302) à un numéro de référence respectif.

15. Procédé selon la revendication 4, dans lequel :

la première référence est représentative d'une durée de temps nécessaire pour charger la première plaque (301) ayant la capacité initiale à une première référence ;
la seconde référence est représentative d'une durée de temps nécessaire pour charger la seconde plaque (302) ayant la capacité initiale à une seconde référence ;
la première capacité étant une différence entre la première référence et une durée de temps pour charger la première plaque (301) à la première référence ; et
la seconde capacité étant une différence entre la seconde référence et une durée de temps pour charger la seconde plaque (302) à la seconde référence.

16. Procédé selon la revendication 4, dans lequel :

la première référence est représentative d'une première tension nécessaire pour charger la première plaque (301) ayant la capacité initiale à une première référence pendant une période de temps déterminée ;
la seconde référence est représentative d'une seconde tension nécessaire pour charger la seconde plaque (302) ayant la capacité initiale à une seconde référence pendant la période de temps déterminée ;
la première mesure de capacité étant une différence entre la première référence et une indication de la première tension ; et
la seconde mesure de capacité étant une différence entre la seconde référence et une indication de la seconde tension.

17. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'action de déplacement comprend l'application du capteur (300) sur la surface (99) ou l'application de la surface (99) sur le capteur (300).

18. Procédé selon l'une quelconque des revendications précédentes, dans lequel l'action de comparaison des première et seconde mesures de capacité comprend les actions consistant à :

déterminer si les première et seconde mesures de capacité sont égales ;
indiquer que, si les première et seconde mesures de capacité sont égales, la ligne médiane (101) est détectée.

19. Capteur (300) de détection d'une caractéristique (100) derrière une surface (99), le capteur comprenant :

une première plaque (301) ayant une première capacité et conçue pour former un premier condensateur avec la structure ;
une seconde plaque (302) ayant une seconde capacité et conçue pour former un second condensateur avec la structure ;
un premier circuit de mesure (410A) couplé au premier circuit de mesure (410A) mesurant une première valeur de capacité du premier condensateur ;
un second circuit de mesure (410B) couplé à la seconde plaque (302), le second circuit de mesure (410B) mesurant une seconde valeur de capacité du second condensateur ;
un circuit de comparaison (414) couplé aux premier et second circuits de mesure (410A ; 410B), le capteur étant **caractérisé en ce que** le circuit de comparaison (414) génère un rapport entre les première et seconde valeurs de capacité pour déterminer une ligne médiane de la caractéristique (100) par rapport aux première et seconde plaques (301, 302) et compare une des première et seconde valeurs de capacité à un premier seuil pour déterminer une profondeur de la caractéristique (100) par rapport à la surface (99) ;
une circuiterie de seuil couplée aux premier et second circuits de mesure (410A ; 410B) et configurée pour déterminer si les première et seconde valeurs de capacité sont inférieures au premier seuil pour déterminer (760) si la caractéristique (100) est profonde.

EP 1 745 310 B1

20. Capteur selon la revendication 19, dans lequel la première plaque (301) et la seconde plaque (302) sont positionnées dans approximativement le même plan et espacées et sont conçues pour être situées adjacentes à une surface (99), et dans lequel le circuit de comparaison (414) est configuré pour :

déterminer une variation dans les valeurs de capacité mesurées ;
calculer un rapport entre la variation dans les valeurs de capacité mesurées ; et
comparer les valeurs de capacité mesurées au premier seuil.

21. Capteur selon la revendication 19 ou 20, dans lequel :

la première valeur de capacité représente une différence entre la première capacité et une capacité initiale du premier condensateur ; et
la seconde valeur de capacité représente une différence entre la seconde capacité et une capacité initiale du second condensateur.

22. Capteur selon la revendication 19, dans lequel le circuit de comparaison détermine en outre si les première et seconde valeurs de capacité sont supérieures ou égales au premier seuil pour déterminer si la caractéristique n'est pas profonde.

23. Capteur selon la revendication 19, comprenant en outre un circuit de traitement couplé au circuit de comparaison (414) et couplé pour recevoir la valeur de rapport et pour déterminer si le rapport est dans un intervalle prédéterminé.

24. Capteur selon la revendication 23, comprenant en outre un indicateur (416) couplé au circuit de comparaison (414) de manière à fournir une indication du rapport des capacités.

25. Capteur selon la revendication 23, dans lequel l'indicateur (416) est conçu pour fournir une indication indiquant que le capteur (300) est sur un bord (102) de la structure quand le rapport est dans l'intervalle prédéterminé.

26. Capteur selon la revendication 23, dans lequel l'indicateur (416) est conçu pour fournir une indication indiquant que le capteur (300) est sur une ligne médiane (101) d'une partie de la structure quand le rapport est dans l'intervalle d'un.

27. Capteur selon la revendication 20, comprenant en outre un indicateur couplé au second circuit de comparaison de manière à fournir une indication d'une profondeur d'une caractéristique derrière la surface (99).

28. Capteur selon la revendication 25, comprenant en outre une mémoire stockant une table de consultation et couplée au circuit de traitement, la table de consultation ayant un rapport de transition pour le circuit de traitement, le rapport de transition étant utilisé pour fixer l'intervalle prédéterminé.

29. Capteur selon la revendication 23, comprenant en outre :

une source d'une tension de référence ;
le premier circuit de mesure comprenant un premier index, le premier index indiquant un nombre de cycles d'horloge nécessaires pour charger la première plaque (301) au niveau de tension de référence ; et
le second circuit de mesure comprenant un second index, le second index indiquant un nombre de cycles d'horloge nécessaires pour charger la seconde plaque (302) au niveau de tension de référence.

30. Capteur selon la revendication 29, dans lequel les premier et second circuits de mesure comprennent respectivement :

une source de courant couplée à une plaque respective des première et seconde plaques (301, 302) ;
un interrupteur de décharge couplé à la plaque respective des première et seconde plaques (301, 302) ;
un convertisseur numérique-analogique (DAC) ayant une borne d'entrée couplée pour recevoir un signal de données en provenance du circuit de traitement, et une borne de sortie ; et
un comparateur ayant une première borne d'entrée couplée à la plaque respective des première et seconde plaques (301, 302), une seconde borne d'entrée couplée au DAC, et une borne de sortie fournissant le signal de sortie du circuit de mesure.

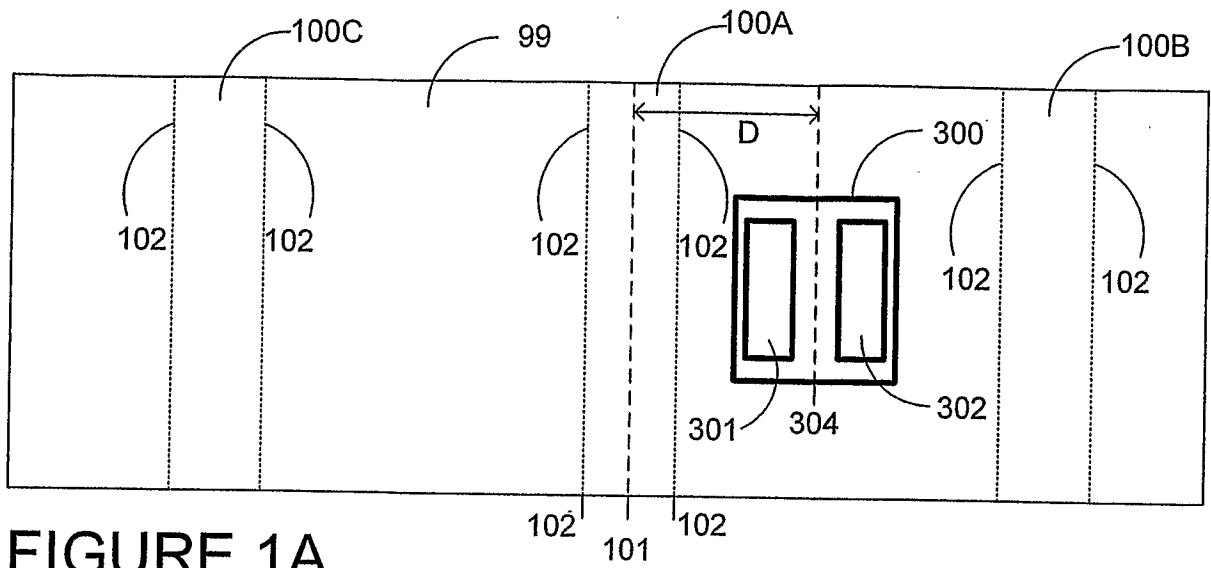


FIGURE 1A

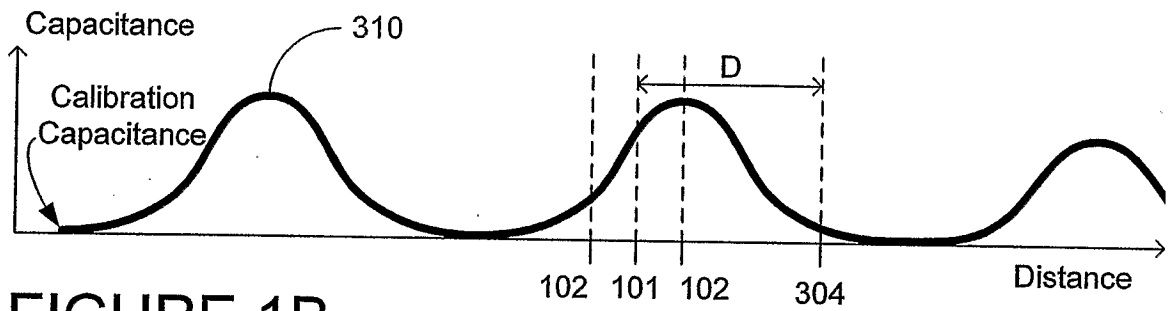


FIGURE 1B

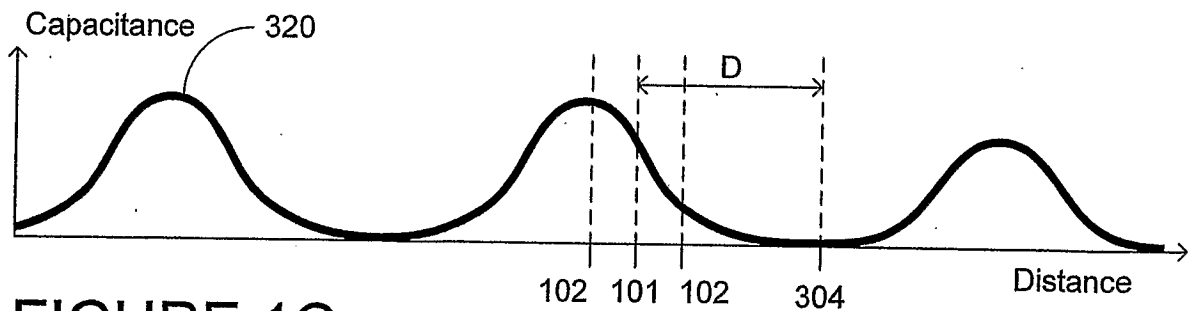


FIGURE 1C

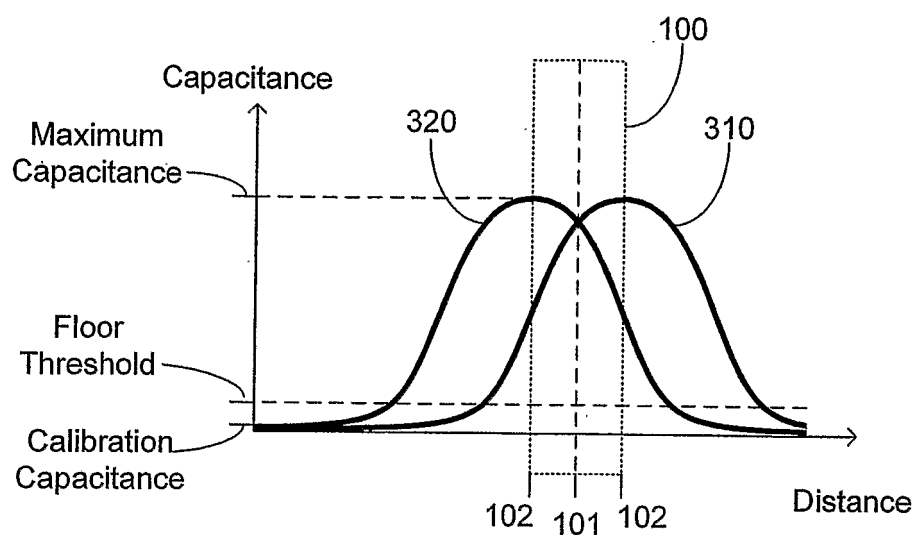


FIGURE 1D

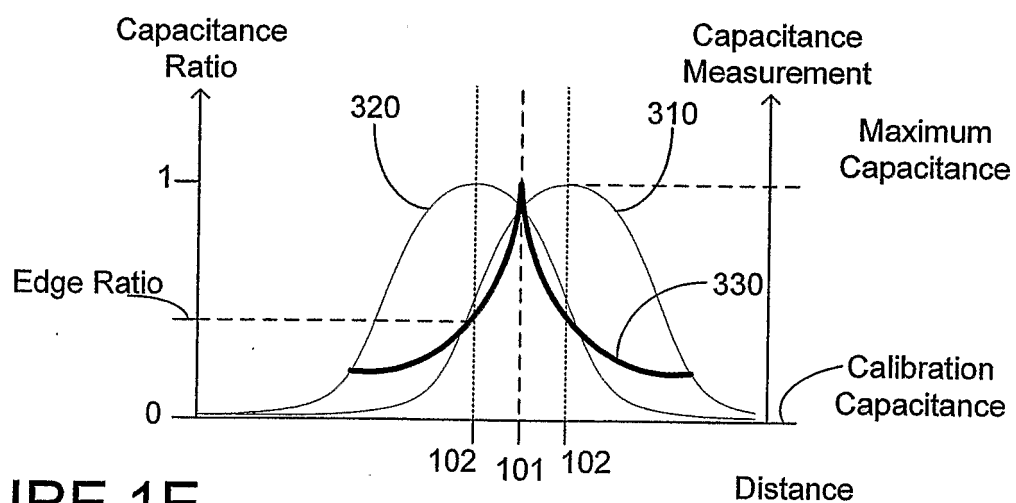


FIGURE 1E

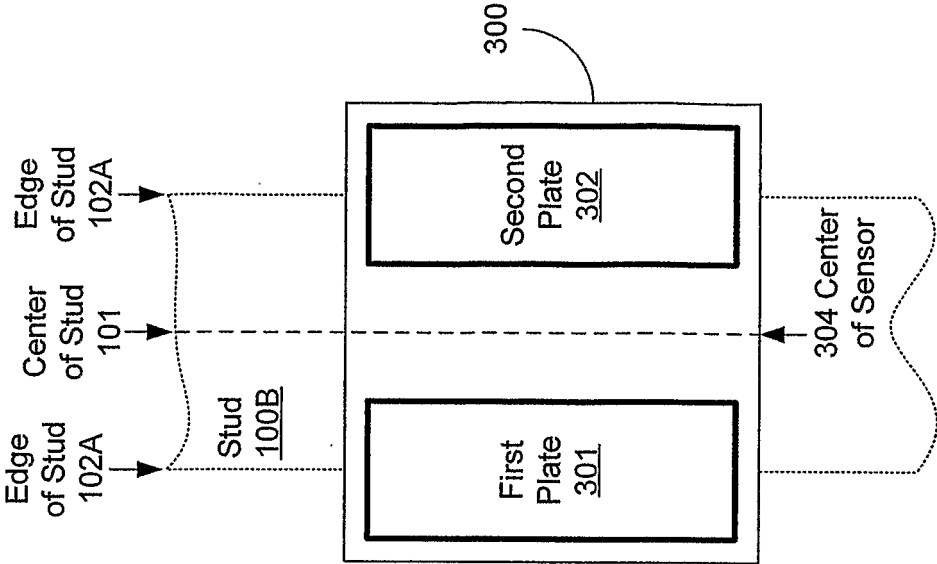


FIGURE 2B

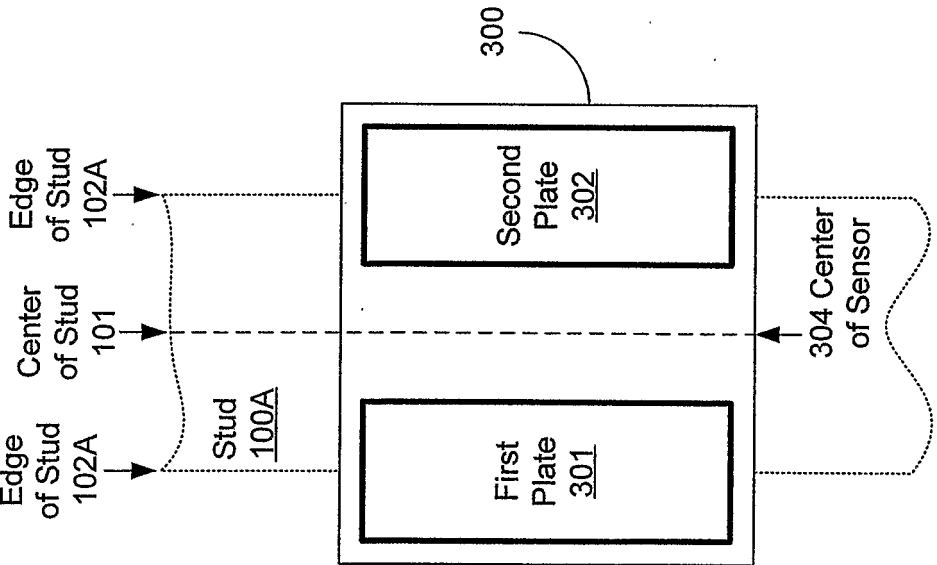


FIGURE 2A

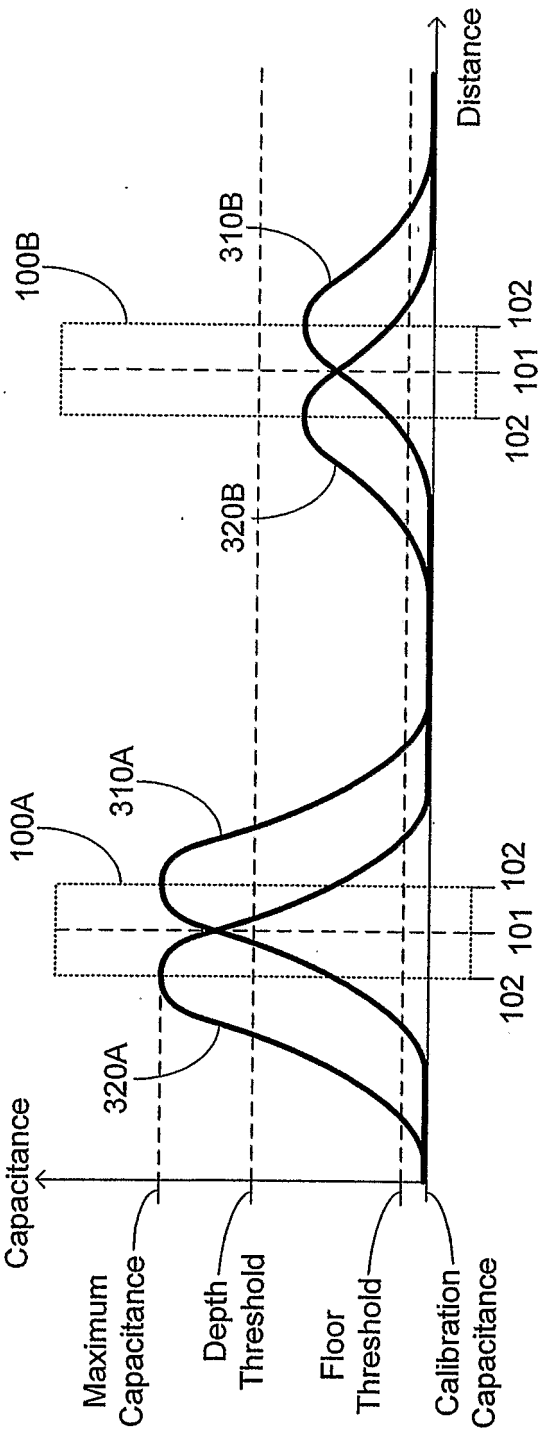


FIGURE 2C

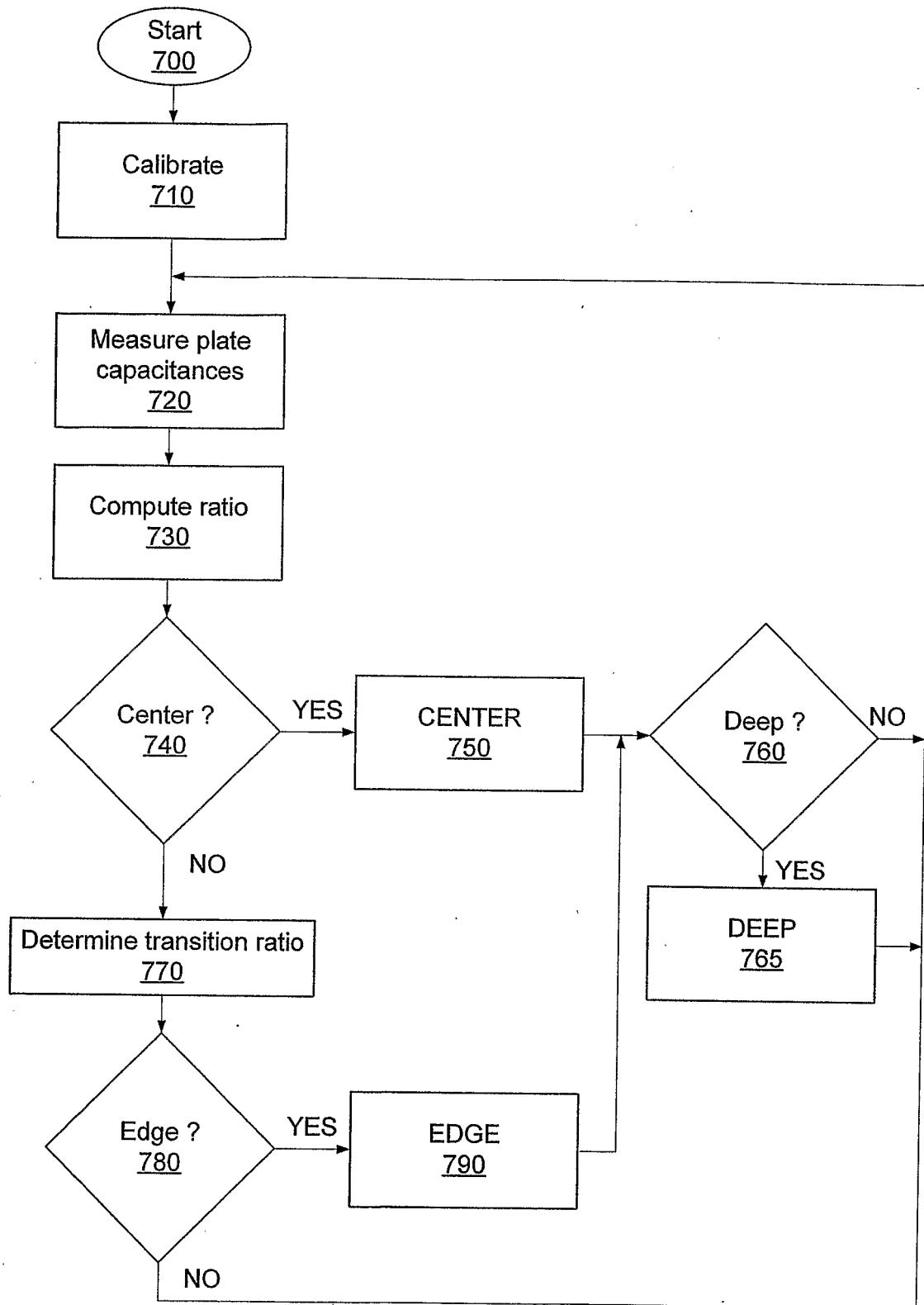


FIGURE 3

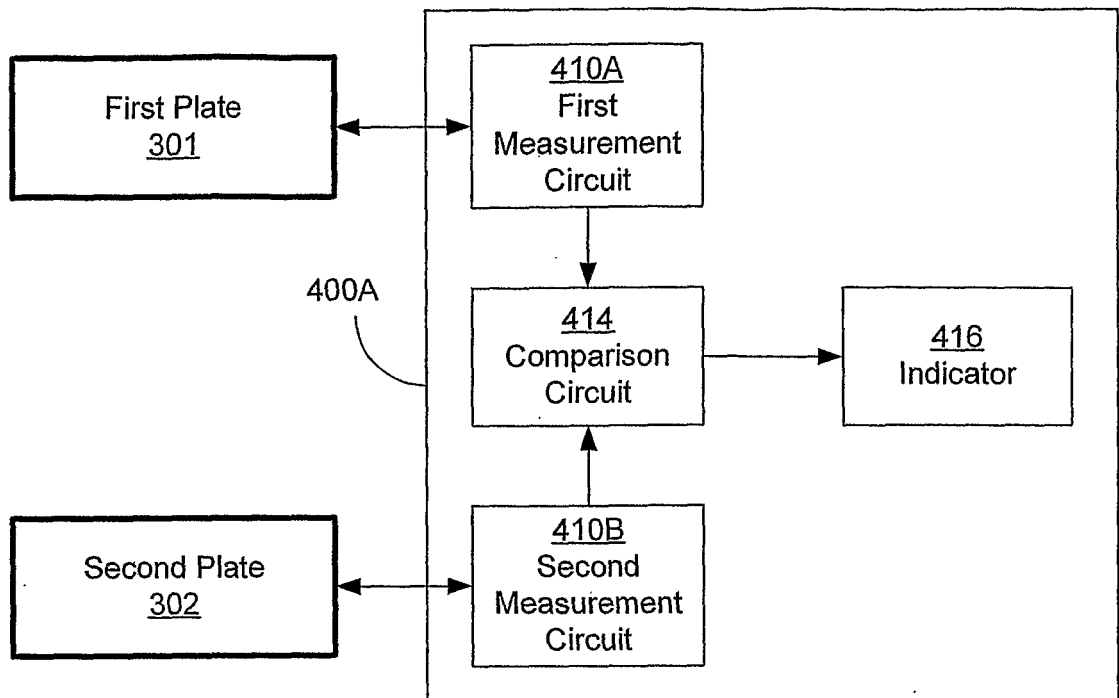
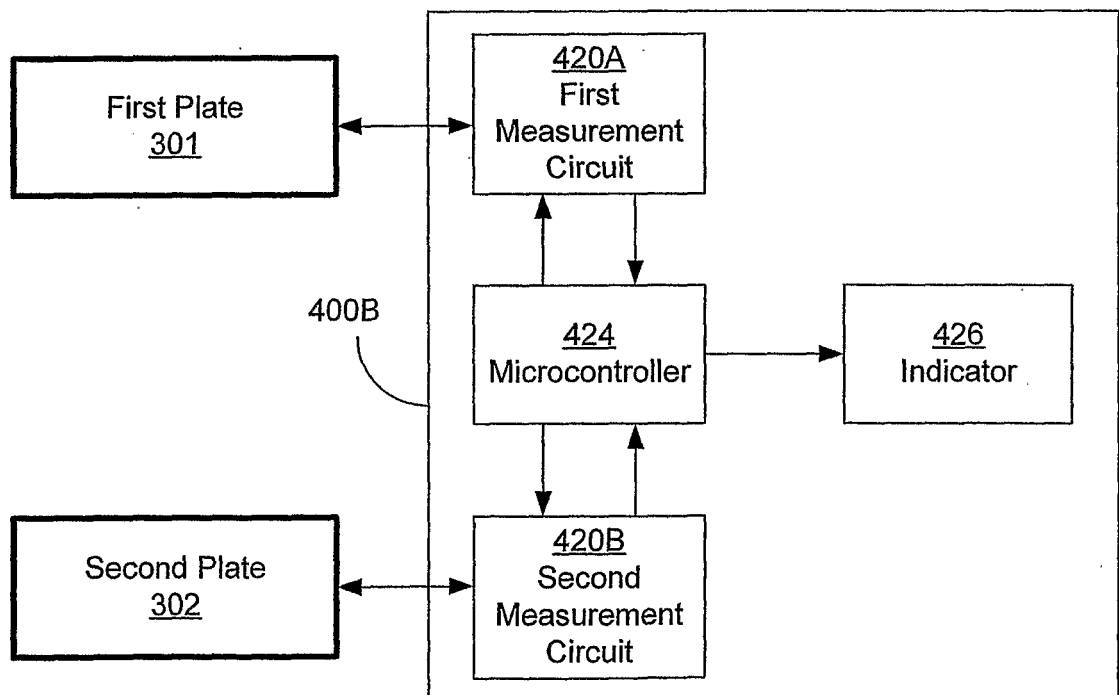


FIG. 4A

FIG. 4B



REFERENCES CITED IN THE DESCRIPTION

This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.

Patent documents cited in the description

- US 4464622 A [0002]
- US 6023159 A [0007]
- US 5917314 A [0008] [0010]
- US 79435604 A [0022]